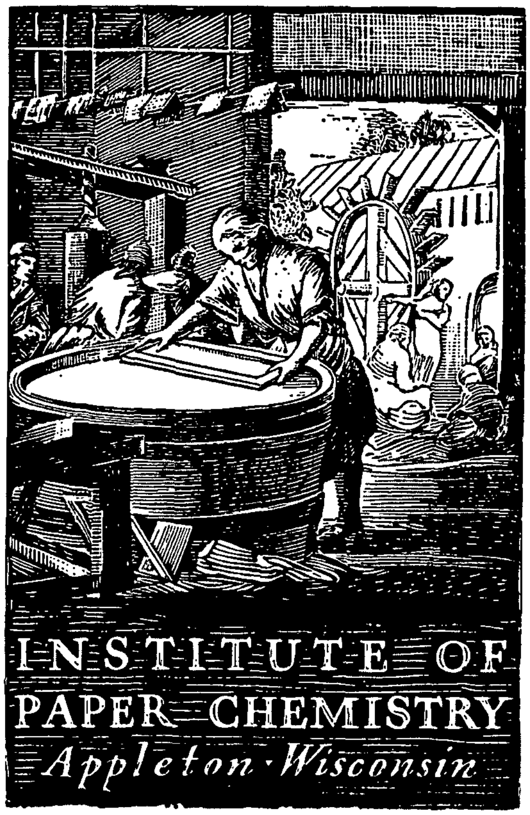
GENERAL



A STUDY OF MEANS TO OPTIMIZE STRENGTH AND DRAINAGE PROPERTIES IN LINERBOARD

Project 3021

Report Two

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

May 5, 1972

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

In pursuing the work described in Progress Report One on this project, the present report examines further the effects of refining, drainage aids, and beater adhesives on the strength, drainage, and water removal properties of a high-yield unbleached kraft liner primary pulp.

Refining the stuff box stock to an equilibrated freeness of 435 ml. C.S.F. was previously found to provide the desired 20-25% increase in bursting strength but at a 30+% reduction in drainage rate compared to that of the mill headbox stock. Drainage aids, including PEI, an anionic polyacrylamide resin, various synthetic cationic polymers, and cationic starch were incorporated into a roughly equivalent pulp (∿ 460 ml. C.S.F.) in an effort to match the drainage properties of the headbox stock, but only one of the products tested improved drainage to an extent approaching the desired level. This was accomplished with 0.2% of a commercial cationic resin (Nalco 636) when used under moderate agitation conditions. However, the increase in drainage rate was accompanied by extensive fiber flocculation which resulted in a sharp decline in strength properties. Cationic potato starch as a drainage aid improved drainage rate to some extent but the level attained fell well below that of the headbox pulp. The filtration resistance of the 460 ml. C.S.F. pulp, was, as expected, notably higher than that of the mill headbox controls and the stuff box pulp. Incorporation of 0.2% of Nalco 636 into the low freeness pulp reduced filtration resistance somewhat but the level attained was notably higher than that of the mill headbox stock, contrary to expectations based on sheet mold drainage and freeness tests. This result was thought to stem from the notable differences

in consistency at which these tests were made and the known dependency of drainage aid effectiveness on concentration. For this reason, filtration resistance test results were considered of questionable practical value in cases involving certain chemical additives. Water removal measurements with the 460 ml. C.S.F. pulp were attempted on the Institute's continuous web former but meaningful data could not be obtained because of limitations of pressure drop and forming length when preparing 42-lb. liner from the well-refined stock. On the basis of the aforementioned results it was tentatively concluded that the combination of extensive refining and drainage aid addition is not a satisfactory approach to achieve the desired balance in strength and drainage properties.

The utilization of 2% of selected beater adhesives (Accostrength 90 and Kymene 557) in the mill stuff box pulp at a freeness of 740 ml. C.S.F. was previously shown to provide the desired improvements in strength properties without appreciable loss in drainage rate. These agents also had little effect on filtration resistance and on water removal properties. The strength improvements were somewhat less dramatic at the 0.5 and 1.0% addition levels (based on fiber) and, under these conditions, Kymene provided the better results. Hence, the addition of beater adhesives to the high-freeness stuff box pulp was indicated to be one means of achieving the desired strength and drainage properties.

The third and final series of tests utilized a moderately refined pulp (630 ml. C.S.F.) equivalent to the mill headbox stock. The results revealed that 23% improvements in bursting strength were attained through incorporation of 0.5% of Kymene 557 alone or through addition of 2% of cationic potato starch plus 0.03% of drainage aid. These strength improvements were achieved with little apparent sacrifice in drainage properties. The filtration resistance data for this series presented a number of contradictions, particularly in those cases which utilized drainage aids. This was again attributed to the notable difference in consistency at which these tests were conducted. The water removal tests, with one exception, paralleled the sheet mold drainage properties to the extent that the cationic starch, as a beater adhesive, slowed drainage and water removal somewhat but addition of 0.03% of drainage aid restored both drainage and water removal properties to levels approaching those of the reference 630 ml. C.S.F. control. The addition of 0.5% of Kymene was found to hinder water removal on the web former in contrast to the sheet mold drainage and filtration resistance data which showed at best a very modest increase in resistance. Hence, aside from this anomalous water removal result, the combination of modest refining plus addition of drainage aid and/or beater adhesive appears to offer a desirable balance in properties and, possibly, in economics.

For purposes of convenience, the strength and drainage results described above may be summarized in tabular form as follows:

Pulp	CS Freeness, ml.	Sheet Mold Drainage Rate, ml./sec.	Corrected Mullen, p.s.i.g.
Unrefined stuff box pulp (control)	740	968	79
Mill headbox pulp (control)	640	938	110
Lightly refined stuff box stock (control)	630	896	110
Well-refined stuff box stock	435-460[a]	583-632[a]	133-134[a]
Well-refined stuff box stock + 0.2% of Nalco 636	645	845	104
Unrefined stuff box stock + 2.0% of Accostrength 90	--	882	142
Unrefined stuff box stock + 2% of Kymene 557	--	968	135

Pulp	CS Freeness, ml.	Sheet Mold Drainage Rate, ml./sec.	Corrected Mullen, p.s.i.g.
Lightly refined stuff box stock + 0.5% of Kymene 557	655	896	136
Lightly refined stuff box stock + 2.0% of Sta-Lok 400 + 0.03% of Nalco 636	710	845	136

[a]Separate series of tests on two pulps.

While trade names are mentioned in the course of this report it was not intended to be a comparison of commercial products. New generations of commercial products have been marketed in some cases; hence, the products employed in this investigation may not represent the latest in a series.

INTRODUCTION

This is Progress Report Two on Project 3021 established in cooperation with the Fourdrinier Kraft Board Institute for the purpose of studying means of improving both the drainage and the strength properties of high-yield kraft liner pulp. It was the goal of this phase of the program to attain a 20-25% increase in the bursting strength of the primary stock with no reduction in drainage rate and water removal.

Results presented in Report One indicated that the desired improvement in bursting strength could be achieved by:

1. Refining the stuff box stock to an equilibrated freeness of 435 ml. C.S.F. in which case the drainage rate was reduced 30+% below that of the mill headbox stock, and by
2. Incorporating 2% of a polyacrylamide or a polyamide-polyamine resin into the stuff box stock, in which case the drainage rate was relatively unaffected.

A decrease in drainage rate would be expected in refining the stuff box stock to 435 ml. C.S.F. and, while the magnitude of the decrease was exceptionally large to be compensated for by addition of drainage aids, a number of these products were examined to determine the extent to which they would improve the drainage rate and the results are reported herein.

Of the two approaches described above, the second offers a distinct advantage in drainage rate and, if it can be assumed that the polyacrylamide resin and wet-strength agent which proved effective are acceptable from the standpoint of cost and repulpability, this would seem to be a satisfactory solution to the strength-drainage problem. It is assumed, however, that cost and repulpability may be limiting factors and, hence, the present work examines the effectiveness of these agents and cationic starch at lower addition levels. Consideration is also given to the combination of limited refining, beater adhesives, and drainage aids as outlined in Phase I-C of the proposal. For purposes of clarity, beater adhesives are materials which are added to the papermaking furnish prior to sheet formation for the purpose of improving strength properties. Drainage aids are materials added to the papermaking furnish for the purpose of improving the water-removal properties of the wet web. The latter may be accomplished by flocculation and retention of finely divided materials such as fines and fillers. In some cases, the same material may function as a beater adhesive or a drainage aid, depending upon the addition level employed.

EXPERIMENTAL

HANDSHEET PREPARATIONS

Three pulps were utilized in continuing the studies described in Progress Report One. These were comprised of the following:

1. The mill stuff box stock with an equilibrated freeness of 740 ml. C.S.F.,
2. the reference pulp which was equivalent to the mill headbox stock, 630 ml. C.S.F., and
3. the mill stuff box stock refined to approximately 460 ml. C.F.S.

Each of these pulps was utilized in handsheet preparations following the general procedure given in Report One but omitting the water removal steps. The procedure is repeated here for purposes of convenience.

For each set of sheets the equivalent of 100 grams of pulp was metered into a stainless steel drum containing sufficient tap water to provide an approximate fiber consistency of 0.1%. The temperature was adjusted to 25°C. in all cases. The required amounts of beater adhesive, rosin, alum, and sulfuric acid were added allowing five minutes of stirring for each. All sets in the current work were formed without white water recirculation at pH 6 in the presence of 0.0375% mill rosin and 1% of alum. The beater adhesives were added either before or after the rosin and alum, depending upon the product involved. The final fiber consistency was 0.1%. A 6-liter aliquot of the pulp (nominally equivalent to 42-lb. liner) was then metered into the Rapid-Kothen mold where it was agitated for 10 seconds at either 100 or 260 cycles/min. When used, drainage aids were added directly to the sheet mold immediately prior to the agitation period. After the specified agitation period, the stirrer was stopped and the drainage process started simultaneously. The time required for drainage and the maximum and stabilized vacuum levels were recorded. This process was repeated to obtain average values for the drainage times and vacuum levels. Hence, drainage properties in the sheet mold were measured with a constant volume of 0.1% pulp. The webs formed in this manner also served as basis weight sheets to determine the actual volume of pulp required to produce a sheet equivalent to 42-lb. liner. Seven additional sheets were then formed at the corrected volume for physical strength tests. These sheets were removed from the wire by couching onto blotters and were then pressed between blotters at 50 p.s.i. for 5 min. followed by drying for 7 min. on a steam-heated drum in contact with one blotter. Sheets prepared in this manner were tested for basis weight, caliper, density, Elmendorf tear, Mullen bursting strength, modified ring compression, and tensile strength. All strength test results were corrected to 42-lb. basis weight.

Drainage aids were screened for their potential effectiveness in the 460 ml. C.S.F. pulp by measuring the approximate drainage rates in the sheet mold at several concentrations, stirring rates, and stirring times. Six liters of 0.1% pulp was utilized in these tests the same as was used in the normal handsheet preparations. The drainage aids were comprised of Tydex 12 (polyethylenimine, cationic — Dow Chemical Co.), Nalco 600 and 636 (cationic polymers — Nalco Chemical Co.), Accurac 27 and 32 (anionic and cationic polymers, respectively — American Cyanamid Company), Sta-Lok 400 (cationic potato starch — A. E. Staley Mfg. Co.), and Cato 15 (cationic cornstarch — National Starch & Chemical Corp.). When used at low addition levels, all of these agents were added as 0.1% solutions or suspensions in distilled water. At addition levels in excess of 0.5%, the drainage aid concentration was increased to 0.5 or 1.0% to avoid incorporation of excessive volumes of water in the sheet mold. Addition levels ranged from 0.01 to 4.0% based on fiber weight depending upon the type of product involved. Blank controls were prepared several times during the course of the screening tests. Results are presented in Table I.

On the basis of the information in Table I, Nalco 636 and Sta-Lok 400 were selected for more extensive evaluation since these products provided the most dramatic increase in drainage rate. A few sets of sheets were prepared with Tydex 12 on the basis of its past performance in the liner pulp utilized on Project 2926 (1). In pursuing this work, the effect of floc strength was examined briefly by utilizing two rates of agitation in the sheet mold, i.e., 100 and 260 cycles/min. The time of agitation was fixed at 10 seconds. The effect of the selected drainage aids on the drainage rates and strength properties of the 460 ml. C.S.F. pulp is presented in Table II.

The beater adhesives utilized in this work included Accostrength 90 (anionic polyacrylamide resin — American Cyanamid Company), Kymene 557 (cationic polyamide-polyamine wet strength resin — Hercules, Inc.), and Sta-Lok 400. These agents were prepared as aqueous solutions or dispersions as described in Report One and were added to the mill stuff box stock (740 ml. C.S.F.) at addition levels ranging from 0.5 to 3.0% based on fiber weight. Results are recorded in Table III. The same products were tested in the reference pulp (630 ml. C.S.F.) at addition levels ranging from 0.5 to 2.0% based on fiber. The cationic starch was also utilized in combination with Nalco 636 drainage aid in this series. Results are presented in Table IV.

TABLE I

A COMPARISON OF DRAINAGE AIDS IN REFINED UNBLEACHED KRAFT LINER PULP (460 ML. C.S.F.)

Test No.	Drainage Aid, % based on fiber	Type of Drainage Aid	Stirring Time, sec.	Stirring Rate, cycles/min.	Drainage Time, sec.	Approximate Drainage Rate, ml./sec.
1	None (control)	--	10	100	9.7	619
2	None (control)	--	10	260	9.7	619
3	Tydex 12, 0.02	Cationic	10	100	9.6	625
4	Tydex 12, 0.05	"	10	100	10.1	594
5	Tydex 12, 0.5	"	10	100	9.2	652
6	Tydex 12, 0.5	"	100	100	9.9	606
7	Tydex 12, 0.02	"	10	260	9.6	625
8	Tydex 12, 0.05	"	10	260	10.2	588
9	Tydex 12, 0.5	"	10	260	10.3	583
10	Nalco 600, 0.01	"	10	100	9.1	659
11	Nalco 600, 0.05	"	10	100	9.3	645
12	Nalco 600, 0.2	"	10	100	10.4	577
13	Nalco 600, 0.5	"	10	100	10.2	588
14	Nalco 600, 2.0	"	10	100	10.3	583
15	Nalco 600, 0.01	"	10	260	9.3	645
16	Nalco 600, 0.05	"	10	260	10.2	588
17	Nalco 600, 2.0	"	10	260	10.3	583
18	None (control)	--	10	100	9.2	652
19	None (control)	--	10	260	9.2	652
20	Nalco 636, 0.02	Cationic	10	100	9.2	652
21	Nalco 636, 0.05	"	10	100	8.5	706
22	Nalco 636, 0.1	"	10	100	8.2	732
23	Nalco 636, 0.2	"	10	100	7.0[a]	857
24	Nalco 636, 0.2	"	100	100	8.1	741
25	Nalco 636, 0.02	"	10	260	9.0	667
26	Nalco 636, 0.05	"	10	260	9.4	638
27	Nalco 636, 0.2	"	10	260	8.2	732
28	Nalco 636, 0.3	"	10	260	7.1[a]	845
29	Accurac 27, 0.01	Anionic	10	100	13.6	441
30	Accurac 27, 0.05	"	10	100	13.2	455
31	Accurac 27, 0.1	"	10	100	12.5	480
32	Accurac 27, 0.2	"	10	100	12.1	496
33	Accurac 27, 0.5	"	10	100	11.1	541
34	Accurac 27, 0.01	"	10	260	10.4	577
35	Accurac 27, 0.1	"	10	260	11.2	536
36	Accurac 27, 0.5	"	10	260	10.2	588
37	Accurac 32, 0.01	Cationic	10	100	9.0	667
38	Accurac 32, 0.05	"	10	100	9.7	619
39	Accurac 32, 0.2	"	10	100	10.6	556
40	Accurac 32, 0.5	"	10	100	10.2	588
41	Accurac 32, 0.01	"	10	260	9.1	659
42	Accurac 32, 0.5	"	10	260	10.4	577
43	None (control)	--	10	100	9.6	625
44	Sta-Lok 400, 0.01	Cationic	10	100	9.6	625
45	Sta-Lok 400, 0.05	"	10	100	9.6	625
46	Sta-Lok 400, 0.2	"	10	100	9.7	619
47	Sta-Lok 400, 0.5	"	10	100	9.0	667
48	Sta-Lok 400, 2.0	"	10	100	8.0	750
49	Sta-Lok 400, 4.0	"	10	100	8.2	732
50	Sta-Lok 400, 2.0	"	100	100	9.9	606
51	Sta-Lok 400, 0.5	"	10	260	9.7	600
52	Sta-Lok 400, 2.0	"	10	260	9.1	659
53	Sta-Lok 400, 4.0	"	10	260	9.0	667
54	Cato 15, 0.01	"	10	100	9.6	625
55	Cato 15, 0.05	"	10	100	9.6	625
56	Cato 15, 0.2	"	10	100	10.2	588
57	Cato 15, 0.5	"	10	100	10.1	594
58	Cato 15, 2.0	"	10	100	8.6	698
59	Cato 15, 4.0	"	10	100	8.2	732
60	Cato 15, 0.05	"	100	100	10.4	577
61	Cato 15, 2.0	"	100	100	11.6	517
62	Cato 15, 4.0	"	100	100	9.7	619
63	Cato 15, 0.01	"	10	260	10.4	577
64	Cato 15, 2.0	"	10	260	9.7	619
65	Cato 15, 4.0	"	10	260	9.8	612

[a]Pronounced fiber flocculation was evident in these cases.

Note: The drainage rate of the reference control at 10 sec. and 260 cycles/min. was 896 ml./sec.
The drainage rate of the headbox control under these conditions was 938 ml./sec.
These may be considered target values for the above screening tests.

TABLE II

THE EFFECT OF DRAINAGE AIDS ON REFINED UNBLEACHED KRAFT LINER PULP (460 ML. C.S.F.)

Set No.	Drainage Aid, % based on fiber	Stirring Rate in Mold, cycles/min.	Drainage Time, sec.	Drainage Rate, ml./sec.	Maximum Vacuum, mm.	Stabilized Vacuum Level, mm.	Basis Wt., lb./1000 sq.ft.	Caliper, mils	Density	Elmendorf Tear, g./sheet	Corrected Tear, (42-lb. basis)	Jumbo Mullen Bursting Strength, p.s.i.g.	Corrected Mullen, (42-lb. basis)	Modified Ring Compression, lb./in.	Corrected Ring Compression, (42-lb. basis)	Tensile, lb./in.	Corrected Tensile, (42-lb. basis)
4	None, headbox control	260	6.4	938	45	45	43.6	18.5	2.4	362	349	114	110	19.9	19.2	48.0	46.2
13	Reference control (630 ml. C.S.F.)	260	6.7	896	55	40	43.4	16.3	2.7	386	374	114	110	19.4	18.8	46.3	44.8
14	None (460 ml. C.S.F. control)	260	9.5	632	180	55	43.7	14.6	3.0	407	391	139	133	20.8	19.0	58.2	55.9
14A	None (460 ml. C.S.F. control)	100	9.7	619	160	55	43.5	14.6	3.0	403	389	124	120	21.0	20.4	57.4	55.4
24	Tydex 12, 0.5	260	10.3	583	190	60	44.0	15.1	2.9	418	399	150	143	25.4	24.1	68.0	64.9
25	Tydex 12, 0.5	100	9.3	645	170	55	44.0	14.9	3.0	381	364	143	136	22.9	21.8	64.0	61.1
26	Tydex 12, 2.0	100	10.3	583	170	55	43.8	14.5	3.0	382	366	158	152	26.2	25.1	73.2	70.2
27	Nalco 636, 0.02	260	9.0	667	170	55	43.4	14.5	3.0	418	404	141	136	21.9	21.2	56.5	54.6
28	Nalco 636, 0.02	100	9.2	652	160	55	43.5	14.5	3.0	426	411	130	126	21.0	20.4	55.4	53.5
29	Nalco 636, 0.05	260	9.4	638	170	55	43.6	14.5	3.0	427	411	134	129	21.6	20.7	58.6	56.5
30	Nalco 636, 0.05	100	8.5	706	140	50	43.8	14.3	3.1	403	386	124	119	21.3	20.4	54.7	53.5
31	Nalco 636, 0.2	260	8.0	750	80	40	43.4	14.8	2.9	424	410	123	119	22.2	21.5	51.3	49.7
32	Nalco 636, 0.2	100	7.1	845	50	40	44.2	14.6	3.0	422	401	109	104	20.4	19.4	41.0	39.0
33	Sta-Lok 400, 0.5	260	9.7	619	175	55	43.4	14.7	3.0	411	398	138	134	22.4	21.7	62.7	60.7
34	Sta-Lok 400, 0.5	100	9.0	667	165	55	43.6	14.9	2.9	392	378	129	124	21.8	20.9	62.3	60.0
35	Sta-Lok 400, 2.0	260	9.0	667	130	45	43.5	15.0	2.9	371	358	130	125	22.8	22.1	61.9	59.8
36	Sta-Lok 400, 2.0	100	8.0	750	90	45	43.3	14.4	3.0	352	341	132	128	21.4	20.8	55.3	53.6

Note: The values listed above for Set 14 represent the average for two sets of handsheets.

TABLE III

THE EFFECT OF SELECTED BEATER ADHESIVES ON UNBLEACHED KRAFT LINER STUFF BOX STOCK (740 ML. C.S.F.)

Set No.	Beater Adhesive, % based on fiber	Stirring Rate, cycles/min.	Drainage Time, sec.	Drainage Rate, ml./sec.	Maximum Vacuum, mm.	Stabilized Vacuum Level, mm.	Basis Wt., lb./1000 sq.ft.	Caliper, mils	Density	Elmendorf Tear, g./sheet	Corrected Tear, (42-lb. basis)	Jumbo Mullen Bursting Strength, p.s.i.g.	Corrected Mullen, (42-lb. basis)	Modified Ring Compression, lb./in.	Corrected Ring Compression, (42-lb. basis)	Tensile, lb./in.	Corrected Tensile, (42-lb. basis)
3	Stuff box control (740 ml. C.S.F.)	260	6.2	968	40	40	43.4	19.5	2.2	352	341	82	79	15.3	14.8	36.2	35.0
3A	Stuff box control	100	6.3	952	40	35	42.2	19.1	2.2	314	313	73	73	13.9	13.3	31.4	31.2
4	Headbox control (640 ml. C.S.F.)	260	6.4	938	45	45	43.6	18.5	2.4	362	349	114	110	19.9	19.2	48.0	46.2
13	Reference control (630 ml. C.S.F.)	260	6.7	896	55	40	43.4	16.3	2.7	386	374	114	110	19.4	18.3	46.3	44.8
13A	Reference control	100	6.8	882	50	40	43.4	16.0	2.7	426	412	119	114	19.8	19.2	48.6	46.7
37	Accostrength 90, 0.5[a]	260	6.3	952	40	35	44.7	19.6	2.3	386	363	103	97	19.2	18.0	43.6	41.0
38	Accostrength 90, 1.0[a]	260	6.2	968	40	35	44.6	19.5	2.3	435	410	119	112	21.1	19.8	45.6	43.0
15	Accostrength 90, 2.0[a]	260	6.8	882	40	35	43.4	18.0	2.4	398	385	147	142	19.2	18.6	54.6	53.1
39	Accostrength 90, 0.5[a]	100	6.2	968	40	35	42.2	18.8	2.2	358	356	100	100	17.2	17.0	41.1	40.9
40	Accostrength 90, 1.0[a]	100	6.2	968	40	35	42.6	18.8	2.3	416	410	109	107	18.8	18.5	45.8	45.2
19	Sta-Lok 400, 2.0[a]	260	6.5	923	40	35	44.5	19.5	2.3	432	408	120	113	18.3	17.3	54.4	51.3
41	Sta-Lok 400, 3.0[a]	260	6.5	923	40	35	43.4	18.5	2.3	416	403	122	118	18.1	17.9	51.3	50.9
42	Sta-Lok 400, 2.0[a]	100	6.3	952	40	35	43.0	19.1	2.3	426	416	125	122	18.6	18.2	45.8	44.7
43	Sta-Lok 400, 3.0[a]	100	6.1	984	40	35	42.8	18.3	2.3	408	400	126	124	17.9	17.5	51.1	50.2
44	Kymene 557, 0.5[b]	260	6.2	968	40	35	42.4	18.8	2.3	386	382	105	104	18.4	18.2	44.4	44.0
45	Kymene 557, 1.0[b]	260	6.2	968	40	35	43.4	18.7	2.3	413	400	128	124	20.6	20.0	51.8	50.1
23	Kymene 557, 2.0[b]	260	6.2	968	40	35	43.4	18.3	2.4	408	395	139	135	21.3	20.6	55.5	53.7
46	Kymene 557, 0.5[b]	100	6.2	968	40	35	42.2	19.3	2.3	365	363	93	93	17.7	17.5	43.8	43.6
47	Kymene 557, 1.0[b]	100	6.2	968	40	35	43.4	18.5	2.3	414	401	118	114	20.5	19.9	52.3	50.6

[a]The order of addition in these sets was rosin, alum, sulfuric acid, and beater adhesive.

[b]The order of addition in these sets was beater adhesive, rosin, alum, and sulfuric acid.

TABLE IV

THE EFFECT OF BEATER ADHESIVES AND DRAINAGE AIDS ON LIGHTLY REFINED UNBLEACHED KRAFT LINER PULP (630 ML. C.S.F.)

Set No.	Beater Additive, % based on fiber	Stirring Rate, cycles/min.	Drainage Time, sec.	Drainage Rate, ml./sec.	Maximum Vacuum, mm.	Stabilized Vacuum Level, mm.	Basis Wt., lb./1000 sq.ft.	Caliper, mils	Density	Elmendorf Tear, g./sheet	Corrected Tear, (42-lb. basis)	Jumbo Mullen Bursting Strength, p.s.i.g.	Corrected Mullen, (42-lb. basis)	Modified Ring Compression, lb./in.	Corrected Ring Compression, (42-lb. basis)	Tensile, lb./in.	Corrected Tensile, (42-lb. basis)
4	Headbox control (640 ml. C.S.F.)	260	6.4	938	45	45	43.6	18.5	2.4	362	349	114	110	19.9	19.2	48.0	46.2
13	Reference control (630 ml. C.S.F.)	260	6.7	896	55	40	43.4	16.3	2.7	386	374	114	110	19.4	18.8	46.3	44.8
13A	Reference control (630 ml. C.S.F.)	100	6.8	882	50	40	43.4	16.0	2.7	426	412	119	114	19.8	19.2	48.6	46.7
48	Accostrength 90, 1.0[a]	260	7.3	822	70	40	44.4	15.7	2.8	456	431	135	128	22.9	21.8	57.0	53.9
49	Kymene 557, 0.5[b]	260	6.7	896	65	40	43.3	16.4	2.6	438	425	140	136	22.4	21.7	57.6	55.9
50	Kymene 557, 1.0[b]	260	7.1	845	70	40	43.4	15.6	2.8	424	410	156	151	23.8	23.1	64.6	62.5
51	Sta-Lok 400, 1.0[a]	260	6.9	870	70	40	42.3	16.1	2.6	426	423	131	130	19.9	19.7	53.5	53.1
52	Sta-Lok 400, 2.0[a]	260	7.5	800	60	40	44.7	16.5	2.7	419	394	145	136	24.0	22.6	63.4	59.6
53	Sta-Lok 400, 2.0 + Nalco 636, 0.03[c]	260	7.1	845	45	40	44.7	16.5	2.7	462	434	145	136	24.9	23.4	60.3	56.7
54	Sta-Lok 400, 2.0 + Nalco 636, 0.03[c]	100	6.7	896	50	40	44.2	16.6	2.7	411	391	139	132	23.1	22.0	56.9	54.1
55	Sta-Lok 400, 2.0 + Nalco 636, 0.05[c]	100	6.6	909	45	35	43.6	16.2	2.7	413	398	133	128	23.1	22.3	48.6	46.8

[a] The order of addition in these sets was rosin, alum, sulfuric acid, and beater adhesive.

[b] The order of addition in these sets was beater adhesive, rosin, alum, and sulfuric acid.

[c] The order of addition in these sets was rosin, alum, sulfuric acid, beater adhesive, and drainage aid.

FILTRATION RESISTANCE AND FREENESS MEASUREMENTS

Filtration resistance for selected samples of pulp was measured in accordance with the descriptions given in Report One. The samples tested were selected on the basis of the sheet mold drainage and sheet strength properties and, for the most part, these samples represented optimum or near optimum conditions. These included the mill stuff box stock with 2% of added Kymene 557 or Accostrength 90; the reference (630 ml. C.S.F.) pulp with 0.5-2.0% of Kymene 557, Accostrength 90, or Sta-Lok 400 starch and combinations of Sta-Lok 400 with low percentage of Nalco 636. Also included was the low freeness pulp with and without drainage aid. Canadian freeness was measured on most of the samples tested for filtration resistance. In conducting both the filtration resistance and freeness tests, the order of addition of additives was the same as that used in handsheet preparations. Filtration resistance and freeness results are summarized in Table V. Filtration resistance as a function of pressure drop is shown in Fig. 1-3.

WATER REMOVAL DETERMINATIONS

As was indicated in Progress Report One on this project, the sheet mold drainage device proved inadequate for measuring water removal. Hence, as the final step in the current program, water removal properties were measured under dynamic conditions on the Institute's continuous web former. A description of the web former has been given by Chang (2). Because the supply of pulp remaining after the handsheet studies was minimal, the water removal tests were limited to those pulps and conditions showing the most promising drainage and strength properties. Measurements were made on the mill stuff box stock and on the reference (630 ml. C.S.F.) pulp. An attempt was made to measure the water removal properties of the

TABLE V

THE EFFECT OF BEATER ADHESIVES AND DRAINAGE AIDS ON THE FREENESS AND FILTRATION RESISTANCE OF UNBLEACHED KRAFT LINER PULP

Set No.	Description	C.S. Freeness, ml.	Filtration Resistance, $\underline{R} \times 10^{-8}$, cm./g. Pressure Drop, $\underline{\Delta P}$, cm. H_2O: 10	20	30	40	50	60	70	80	90
14	Stuff box stock refined to 460 ml. C.S.F. (control)	460	1.69	2.55	3.31	4.06	4.78	5.46	6.13	6.79	7.42
31	Stuff box stock refined to 460 ml. C.S.F. with 0.2% of added Nalco 636	645	1.31	2.08	2.66	3.22	3.75	4.26	4.76	5.24	5.73
3	Stuff box control	740	0.24	0.34	0.42	0.50	0.56	0.63	0.69	0.75	0.81
15	Stuff box stock with 2% of Accostrength 90	--	0.24	0.33	0.41	0.48	0.55	0.61	0.67	0.73	0.78
23	Stuff box stock with 2% of Kymene 557	--	0.21	0.30	0.37	0.43	0.49	0.54	0.59	0.64	0.69
4	Headbox stock, control	640	0.58	0.88	1.14	1.38	1.60	1.82	2.03	2.23	2.43
13	Reference pulp, control	630	0.62	0.90	1.15	1.36	1.57	1.78	1.99	2.18	2.36
48	Reference pulp with 1% of Accostrength 90	--	0.58	0.93	1.23	1.51	1.78	2.04	2.29	2.52	2.75
49	Reference pulp with 0.5% of Kymene 557	655	0.52	0.85	1.12	1.38	1.62	1.85	2.07	2.28	2.50
50	Reference pulp with 1% of Kymene 557	650	0.56	0.89	1.17	1.42	1.66	1.89	2.11	2.33	2.53
52	Rbference pulp with 2% of Sta-Lok 400	695	0.46	0.75	0.99	1.22	1.43	1.62	1.82	2.01	2.19
53	Reference pulp with 2% of Sta-Lok 400 + 0.03% of Nalco 636	710	0.70	1.07	1.39	1.68	1.95	2.20	2.46	2.71	2.94
55	Reference pulp with 2% of Sta-Lok 400 + 0.05% of Nalco 636	710	0.62	0.97	1.25	1.52	1.77	2.02	2.25	2.47	2.68

Note: All pulps contained 0.0375% of rosin size, 1.0% of alum (based on fiber), plus sufficient sulfuric acid to adjust the pH to 6. The order of addition was the same as that used in handsheet preparations.

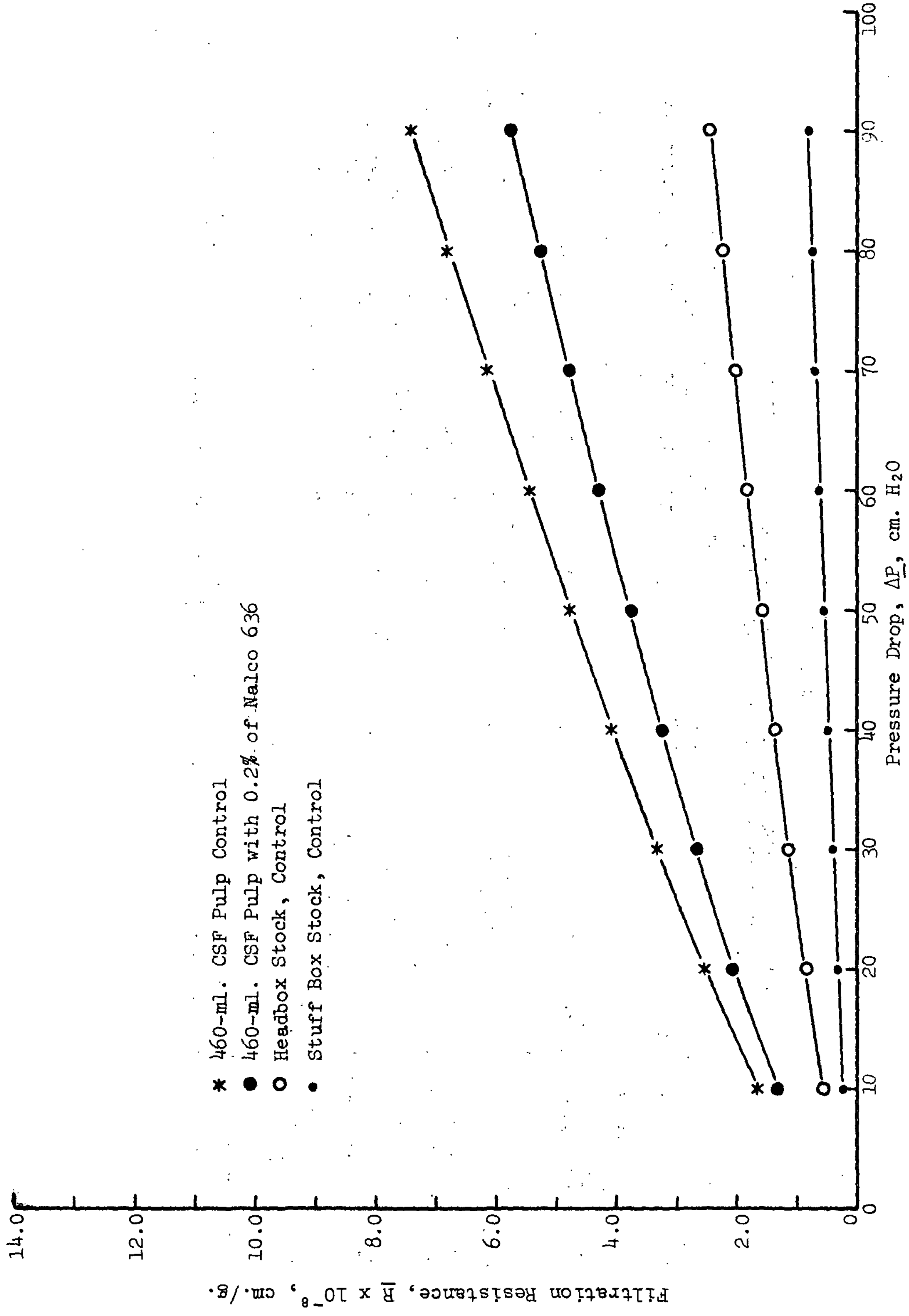

Figure 1. The Effect of Drainage Aid on the Filtration Resistance of the Low-Freeness Pulp (460 and CSF)

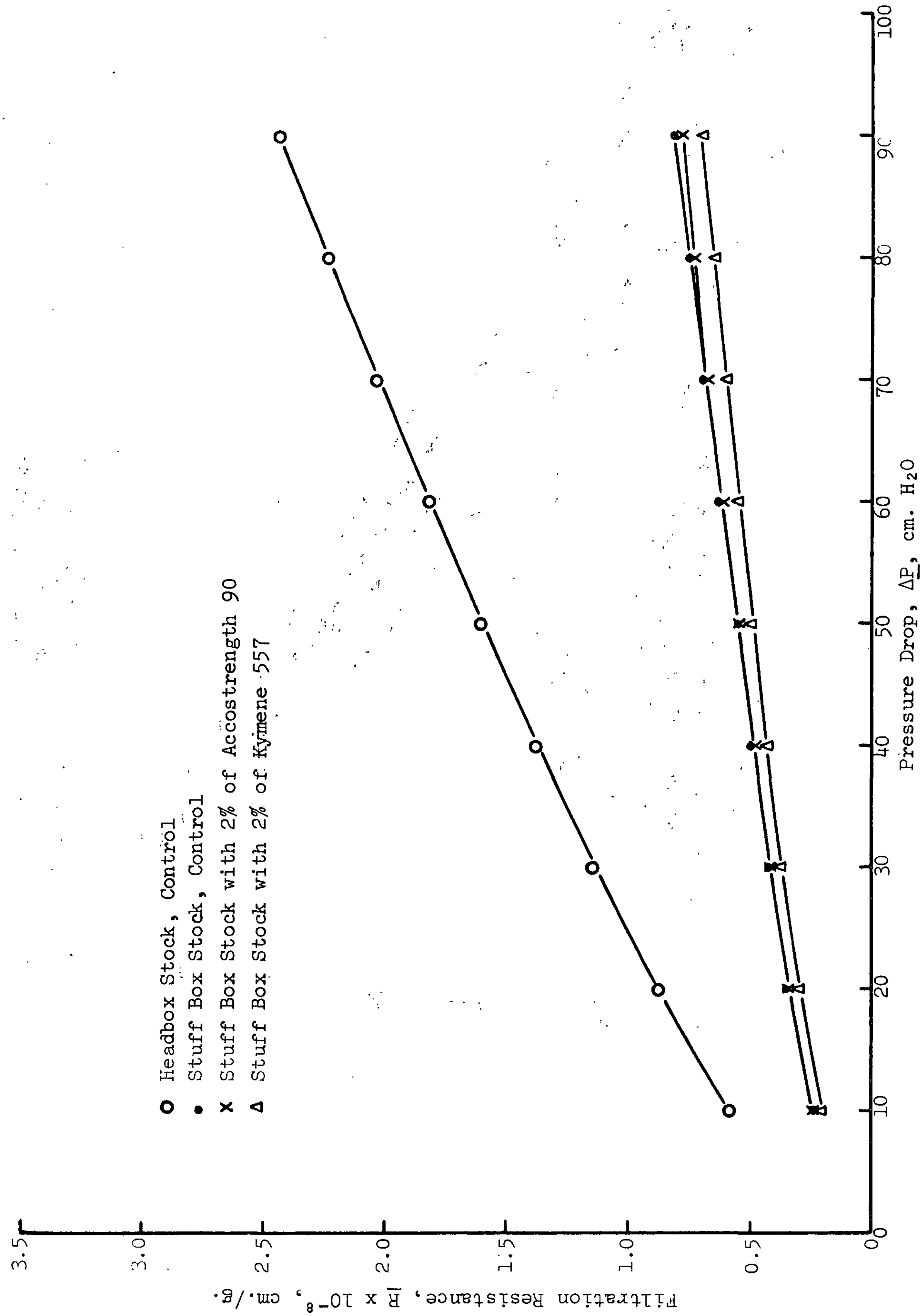

Figure 2. The Effect of Beater Adhesives on the Filtration Resistance of Stuff Box Stock (740 ml. CSF)

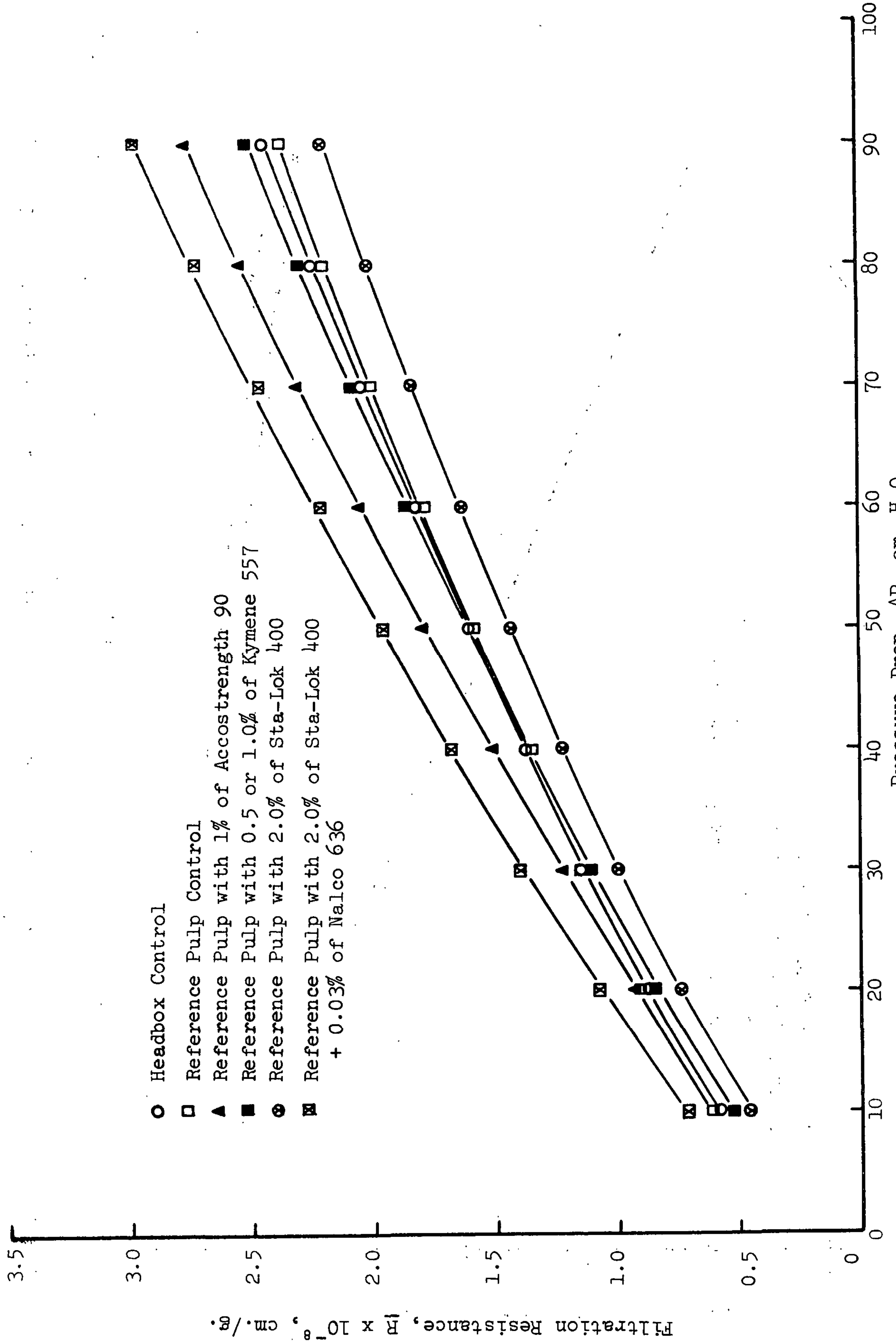

Figure 3. The Effect of Beater Adhesives and Drainage Aids on the Filtration Resistance of the Reference Pulp (630 ml. CSF)

low freeness (460 ml. C.S.F.) pulp but meaningful data could not be obtained because the forming length at maximum pressure drop extended far beyond the normal forming zone when producing the equivalent of 42-lb. liner. The web former was operated without drying with an 80 x 72 semitwill wire at speeds of 6.52 or 6.62 f.p.m. at a constant nip pressure which was in the range of commercial practice. Changes in stock freeness necessitated some changes on the web former but conditions were maintained constant for a given pulp. When used, beater adhesives were incorporated into the stock tank either before or after the addition of rosin size and alum allowing five minutes of stirring for each. The order of addition depended upon the additive involved and was the same as that used in handsheet preparations. The pH was adjusted to 5.8-6.2 with dilute sulfuric acid and the temperature of the stock flowing onto the wire fell within the range 50-55°F. in all cases. Nalco 636, as a drainage aid, was metered into the stock line under conditions of minimum turbulence before passing onto the wire. Water removal was measured after reaching steady state by removing samples of the web before and immediately after the presses. Web solids were determined by weight difference after taking the samples to dryness at 105°C. Results of these measurements are summarized in Table VI.

TABLE VI

THE EFFECT OF ADDITIVES ON WATER REMOVAL PROPERTIES USING THE CONTINUOUS WEB FORMER

Run No.	Description — Beater Additives, % (based on fiber)	Machine Speed, ft./min.	Stock Tank Consistency, %	Pressure Drop, ΔP, cm. H_2O	Forming Length, cm.	Web Solids Content Off Wire, %	Web Solids Content Off Presses, %
1	Stuff box control (740 ml. C.S.F.)	6.62	0.725	10	10.9	5.8	23.0
				20	9.6	6.8	23.8
2	Stuff box stock, Accostrength 90, 2.0	6.62	0.725	10	11.5	5.5	23.8
				20	10.2	7.2	24.8
3	Stuff box stock, Kymene 557, 2.0	6.62	0.798	10	11.0	6.2	23.5
				20	9.7	7.2	24.1
				30	8.9	9.5	--
4	Reference pulp control (630 ml. C.S.F.)	6.52	0.52	50	10.5	10.1	25.5
				60	9.6	11.9	26.9
5	Reference pulp, Sta-Lok 400, 2.0	6.52	0.52	50	11.7	10.3	23.2
				60	10.4	10.8	24.0
6	Reference pulp, Sta-Lok 400, 2.0 + Nalco 636, 0.03	6.52	0.52	50	11.0	10.2	25.2
				60	10.0	11.8	26.4
7	Reference pulp, Kymene 557, 0.5	6.52	0.62	60	Beyond forming zone		
				70	11.0	10.9	25.6

Notes: All runs incorporated the use of 0.0375% rosin size and 1% of alum based on fiber.
The order of addition in Runs 2, 5, and 6 was rosin, alum, followed by beater additives.
The order of addition in Runs 3 and 7 was Kymene 557, followed by rosin and alum.

The web former was operated at a nip pressure of 24 p.s.i. in all cases.
The forming consistency was 0.1-0.2%; the pH was 5.8-6.2; the stock temperature was 50-55°F.
The wire used was an 80x72 semitwill.

DISCUSSION OF RESULTS

The screening of drainage aids in the low freeness pulp (Table I) led to several unexpected developments. The most notable of these was the poor performance of polyethylenimine (PEI, Tydex 12) as indicated in Tests 3-9. In work carried out earlier on Project 2926 (1), PEI was found to be an effective drainage aid in unbleached kraft liner pulp in most ionic environments and it appears that the most obvious difference between the previous and current sets of experiments was the ionic environment. In the earlier work the pulp was washed with deionized water whereas the stock used in the current study was of high yield (Kappa No. 104) and was diluted directly with tap water without washing. The current conditions would therefore be more representative of mill conditions. The results suggest that the floc strength obtained with PEI in the present series was somewhat lower than that obtained previously in the more idealized environmental systems. The potential effectiveness of PEI in the high yield pulp was indicated by an isolated freeness test in which 0.5% of Tydex 12 was incorporated into the stuff box stock in conjunction with 0.0375% of rosin size and 1% of alum. In that case the freeness increased from 460 to 640 ml. C.S.F., indicating definite floc formation. This again points to the importance of floc strength since any floc formed in handsheet preparations was apparently destroyed by the moderate agitation (10 sec. at 100 cycles/min.) used in the sheet mold drainage tests. Hence, there is evidence to suggest that the performance of drainage aids depends upon pulp purity or yield as well as concentration, shear rate, and other factors.

Of the remaining drainage aids examined (Table I) only Nalco 636 and cationic starch showed any evidence of improving drainage in the sheet mold test. Of these, Nalco 636 provided the most dramatic improvements (Tests 23 and 28) although this was apparently accomplished through pronounced fiber flocculation.

In spite of the obvious flocculation in these cases, the drainage rates fell short of the target values associated with the headbox and reference pulp controls (see footnote, Table I). Both cationic cornstarch (Tests 54-65) and cationic potato starch (Tests 44-53) produced some positive effects with respect to drainage but the potato starch maintained a slight advantage under optimum conditions with respect to stirring time, stirring rate, and addition level. As was found previously, increasing the agitation rate decreased the efficiency of the drainage aids. This is indicated again in Table II, which includes the effects of selected drainage aids on strength properties. It becomes apparent from the results in Table II that those conditions leading to optimum drainage in the presence of Nalco 636 also led to minimum strength. In fact, the bursting strength attained at maximum drainage (Set 32) is lower than that of the headbox and reference controls (Sets 4 and 13). In effect, the advantage in strength gained by extensive refining was more than offset by gross fiber flocculation. In making these comparisons it should be borne in mind that the drainage rate was reduced approximately 30% by refining and this represents a difficult condition to overcome with drainage aids without incurring adverse fiber flocculation. Cationic potato starch (Set 36) provided better strength properties than Nalco 636 but the drainage rate fell short of the target value of approximately 900 ml./sec. Some of the more interesting results in this series, in so far as strength properties are concerned, were produced by PEI (Tydex 12, Sets 24-26). This material afforded very substantial increases in burst, ring compression, and tensile strength but had little or no effect on drainage. Tear strength proved quite erratic in the presence of the drainage aids but was generally higher in the presence of 0.05 and 0.2% of Nalco 636, possibly because bonding strength was adversely affected.

The expected decrease in filtration resistance with addition of Nalco 636 to the low freeness pulp did not materialize as shown in Table V and Fig. 1. Some drop in resistance is indicated but the values were expected to approach those of the headbox stock controls. It should be borne in mind that the filtration resistance test is made at a fiber consistency of 0.01% compared to 0.1% in the sheet mold drainage studies, 0.3% in the freeness test, and 0.5 to 0.7% on the commercial paper machine. These differences in consistency could easily affect the performance of drainage aids which are known to depend upon concentration and shear rate. Hence, filtration resistance data for systems involving some additive and, in particular, drainage aids could be quite misleading. It may be noted in Table V that the freeness values for the 460 pulp (Sets 14 and 31) show a much greater response to the presence of the drainage aid than is indicated in the filtration resistance data. This again may reflect differences in concentration.

Several beater adhesives produced the desired increase in bursting strength in the mill stuff box stock when added in an amount equivalent to 2% based on fiber (Sets 15 and 23 in Table III). These agents (Accostrength 90 and Kymene 557) increased burst in excess of 70% over the stuff box controls and 22-29% over the headbox controls. Rather substantial improvements in ring compression and tensile strength were also attained over the stuff box controls. The strength improvements were somewhat less dramatic at the 0.5 and 1.0% addition levels and, under these conditions, Kymene provided the better strength properties. Decreasing the agitation rate in the sheet mold tended to reduce the effectiveness of these agents, possibly due to slightly poorer sheet formation. Tear resistance tended to be higher in the presence of the beater adhesives, thereby providing a rather unique combination of properties. Cationic potato starch is shown to provide sizable improvements over the stuff box controls at the lower addition rate but the desired improvements over the headbox stock were not attained with this agent. The filtration resistance data for the stuff box stock (Table V, Fig. 2) indicate that incorporation of 2% of Kymene and Accostrength had little effect on drainage properties maintaining a level well below that of the mill headbox stock. This is also indicated in the sheet mold drainage properties for Kymene (Table III), although Accostrength appears to have slowed the stock slightly.

The combination of some refining plus the addition of drainage aids and/or beater adhesives appears to offer a desirable balance in properties and possibly in economics. The results in Table IV show that the addition of 0.5% of Kymene 557 to the 630 ml. C.S.F. reference pulp (Set 49) provides substantial improvements in bursting strength and tensile strength over the headbox and reference controls. Likewise, the combination of 2% of cationic potato starch as a beater adhesive plus 0.03% of Nalco 636 drainage aid (Set 53) provided roughly comparable results with little apparent sacrifice in drainage properties. Ring compression and tear strength were also improved beyond the level of the mill headbox stock under these conditions. Incorporation of 0.05% of the drainage aid (Set 55) tended to improve drainage slightly but at the expense of strength properties. In this case, some evidence of fiber flocculation was apparent. The filtration resistance data for the 630 ml. C.S.F. pulp (Table V, Fig. 3) appear to present a number of contradictions. First of all, incorporation of 2% of Sta-Lok 400 is shown to reduce drainage resistance below that of the headbox and reference pulp controls, an effect which was not indicated in the handsheet studies (Set 52) where a reduction in drainage rate was found. Secondly, the combination of 2% of Sta-Lok 400 plus 0.03% of Nalco

636 is indicated to increase filtration resistance sharply whereas a beneficial effect on drainage was indicated in the sheet mold. This again is believed to reflect differences in the performance of additives due to the significantly different consistencies used in the filtration resistance and sheet mold drainage tests. The freeness data for the same systems differ in trend from both the sheet mold and filtration resistance results. In keeping with the filtration resistance data, incorporation of 2% of cationic starch increased the freeness but, unlike the filtration resistance results, addition of drainage aid further increased the freeness. The freeness test is run at 0.3% consistency under rather quiescent conditions which tend to promote fiber flocculation. Hence, neither filtration resistance nor freeness may be indicative of actual performance on the paper machine when certain additives are utilized.

With one exception, the water removal data in Table VI reflect what might be considered expected trends. In keeping with the sheet mold drainage and filtration resistance results, addition of 2% of Kymene or Accostrength 90 to the mill stuff box pulp had little effect on the water removal properties on the web former (Runs 1-3). With reference to the 630 ml. C.S.F. pulp, the water removal results obtained with Sta-Lok 400 alone and in combination with Nalco 636 (Runs 5 and 6) are in reasonably good agreement with the sheet mold drainage properties in that the addition of 2% of the starch slowed drainage and water removal somewhat but incorporation of 0.03% of drainage aid restored both the drainage and water removal values to levels approaching those of the reference 630 ml. C.S.F. control. The exception is found in Run 7 when 0.5% of Kymene in the reference pulp extended the forming length and necessitated an increase in pressure drop to bring the forming length and web solids to levels approaching those of the reference pulp control. This was not expected on the basis of the sheet mold drainage and filtration resistance results which showed at best a very modest increase in resistance over the controls at higher pressure drops. No plausible explanation for this behavior has been established.

In review, the results obtained in the present study offer several alternatives for attaining the sought after improvements in bursting strength. The available evidence suggests that the combination of extensive refining and drainage aid addition is probably not a satisfactory approach because the reduction in drainage rate associated with the refining could not be offset through addition of drainage aid short of gross fiber flocculation and loss in strength. However, it would appear that incorporation of approximately 2% of selected beater adhesives into the stuff box stock or the addition of beater adhesives and drainage aids to the lightly refined pulp equivalent to the mill headbox stock would provide the desired strength improvements without serious impairment in drainage and water removal properties. Of the beater adhesives tested, Kymene 557 provided the most consistent improvements in strength properties considering both pulps (740 and 630 ml. C.S.F.) and all addition levels. The course selected would, of course, be influenced by economic factors and, from this standpoint, the use of low addition levels in the lightly refined pulp may have the advantage.

FUTURE WORK

The results obtained in the current program suggest several promising approaches for attainment of the desired strength and drainage properties in high-yield unbleached kraft liner pulp. However, the results may not be optimum with respect to the level of refining nor to the type and amount of additives used. Further, the current work was necessarily limited to one high-yield pulp. It is suggested, therefore, that the program be extended to include additional pulps having a range in liquor retention and to include other beater adhesives and drainage aids in consultation with the subcommittee as outlined in modified Proposal 1775.

ACKNOWLEDGMENTS

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